ENGINEERING CASE LIBRARY

ECL 101A

ERNIE KOSSICK (A)

Slowing a Universal Electric Motor

By the Inter-Office Memorandum of May 12, 1966 (Shown in Exhibit 1) the Construction and Air Tool Division of Skil Corporation in Chicago, Illinois asked the Electrical Engineering Department for an electric motor to power a new "concrete vibrator". The vibrator, which looked somewhat like a snake connected to an electric motor (pictured in Exhibit 2) was essentially a "self shaking stick" used by building contractors to vibrate fresh molten concrete so it would pack solidly into forms where it had been poured. The vibration was caused by an eccentric weight inside the head of the "stick" which was spun by the motor through a flexible shaft in the connecting "snake".

Prepared in the Design Division, Department of Mechanical Engineering, by Mr. Karl H. Vesper, with financial support from the National Science Foundation. The helpful cooperation of Mr. Ernie Kossick and Skil Corporation in making this material available is gratefully acknowledged.

PEO No. 310
ASSIGNED TO: Rex Beach
ISSUE No. 1

FLEXIBLE SHAFT DRIVES

Length: 18 inches, 5 ft. and 10 ft. Dia.- 1-1/16 inches.

Construction Features:
1 - 1/4" sq. drive - both ends.
2 - Power capability to transmit max. torque to head without failure.
3 - Life expectancy of 200 hrs. minimum.
4 - Must withstand operating on a diameter equal to 6 times dia. of casing.
5 - Casing must not take a permanent set of over .020 per foot when subjected to a 200 lb. axial load.
6 - Investigate connector for 5 ft. and 10 ft. flex. shafts to make 15 ft. flex. shaft.

VIBRATOR HEADS

Sizes:
1" dia. nominal
1-1/4" " "
1-1/2" " "
1-3/4" " "

Construction Features:
1 - Oil Lubrication
2 - Completely leakproof construction
3 - Bearing life to exceed 200 hours of continuous operation
4 - Hardened exterior to withstand abrasive wear.

MARKET AREA: Construction Equipment

MAJOR COMPETITION: Apollo, Champion, Wyco, Stow, Remington, Thor, Viber, Vibro-Plus, Dart

TARGET LIST PRICE: $193. with 10 ft. core and casing and 1-1/4" head (approx.)

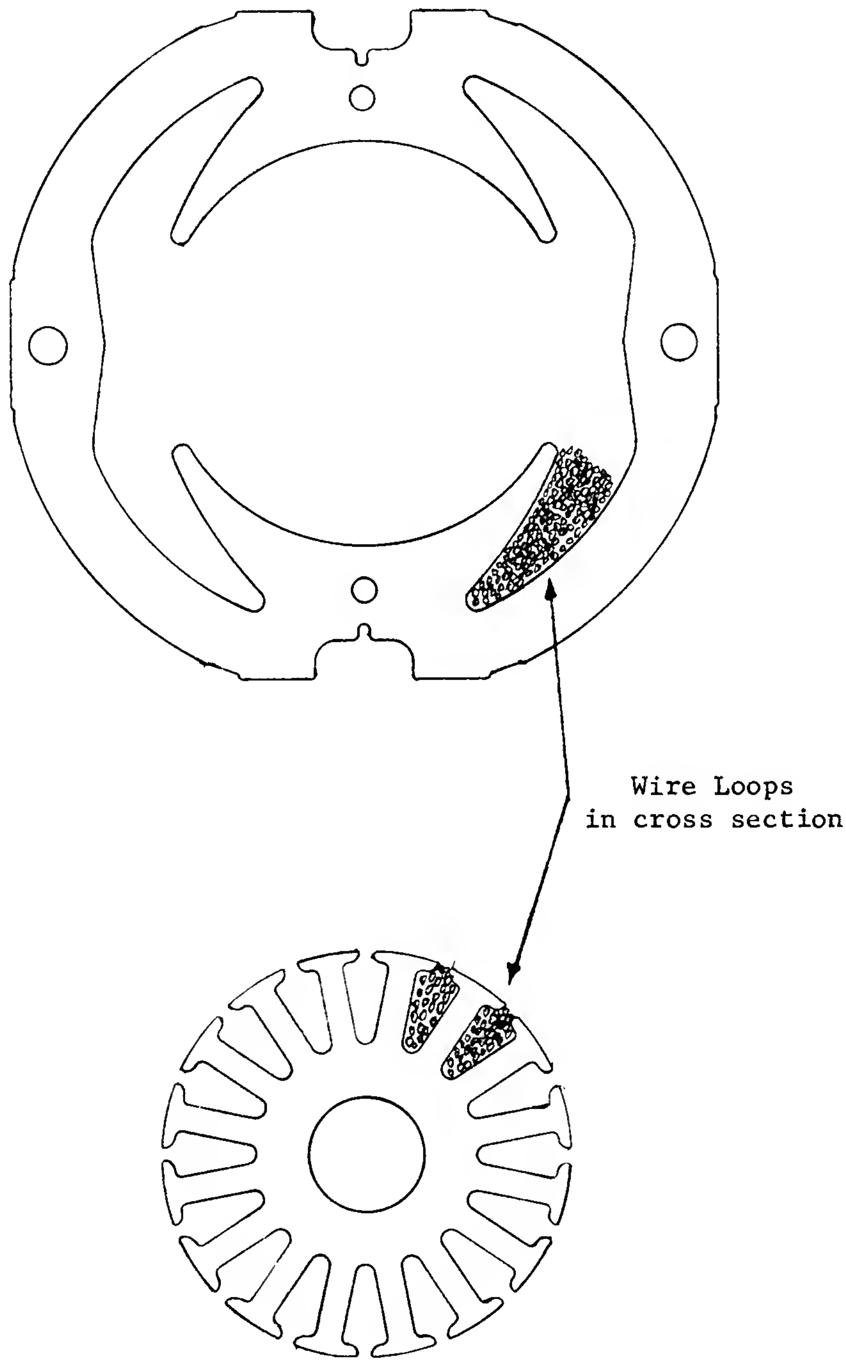
SALES FORECAST: 1,000 per year

TARGET RELEASE DATE: January 30, 1967

Issued by: Elmer F. Etzkorn

EFE:brg

These are stamped from thin sheet iron and piled against one another along the axis of the motor shaft. Coils of wire are looped through the slots as shown. The clearance (air gap) between the armature stack and the field stack after assembly is 0.031 incles total or 0.0155 inches per side.



A universal motor has the field and armature coils wired in series. A commutator is used which keeps the rotor and stator magnetic fields oriented at 90° to one another thereby producing torque, and this is true whether the current is alternating or direct. The electric circuit equation of the motor has three terms which must balance. The applied voltage from the line (V) is opposed by the resistances of field and armature in series ($R_f + F_a$) and by a counter voltage (counter EMF) which is generated by the armature spinning in the magnetic field of the stator. This equation can be written as follows:

$$(1) \quad V = I(R_f + R_a) + \text{Counter EMF}$$

The counter EMF term is determined by properties of the motor as follows:

$$(2) \quad \text{Counter EMF} = \frac{2N_a}{a} P\phi \frac{n}{60} \quad \text{volts}$$

where N_a = number of armature turns (of wire)

P = number of poles (here 2)

a = number of parallel winding paths (here 2)

ϕ = Flux per pole in webers

n = speed in RPM

The flux is produced by the current flowing through the field windings. Since the reluctance of the iron in the flux path is very much smaller than the reluctance of the two air gaps between the field poles and the armature, as a first approximation we may consider that all of the magnetizing force produced by the field is used in overcoming the air gap reluctance. Then the equation for flux is:

$$(3) \quad = 4 \frac{1}{\ell} N_f I A \; 10^{-9}$$

where: ℓ = length of the two air gaps in series in centimeters

N_f = number of field turns per pair of poles

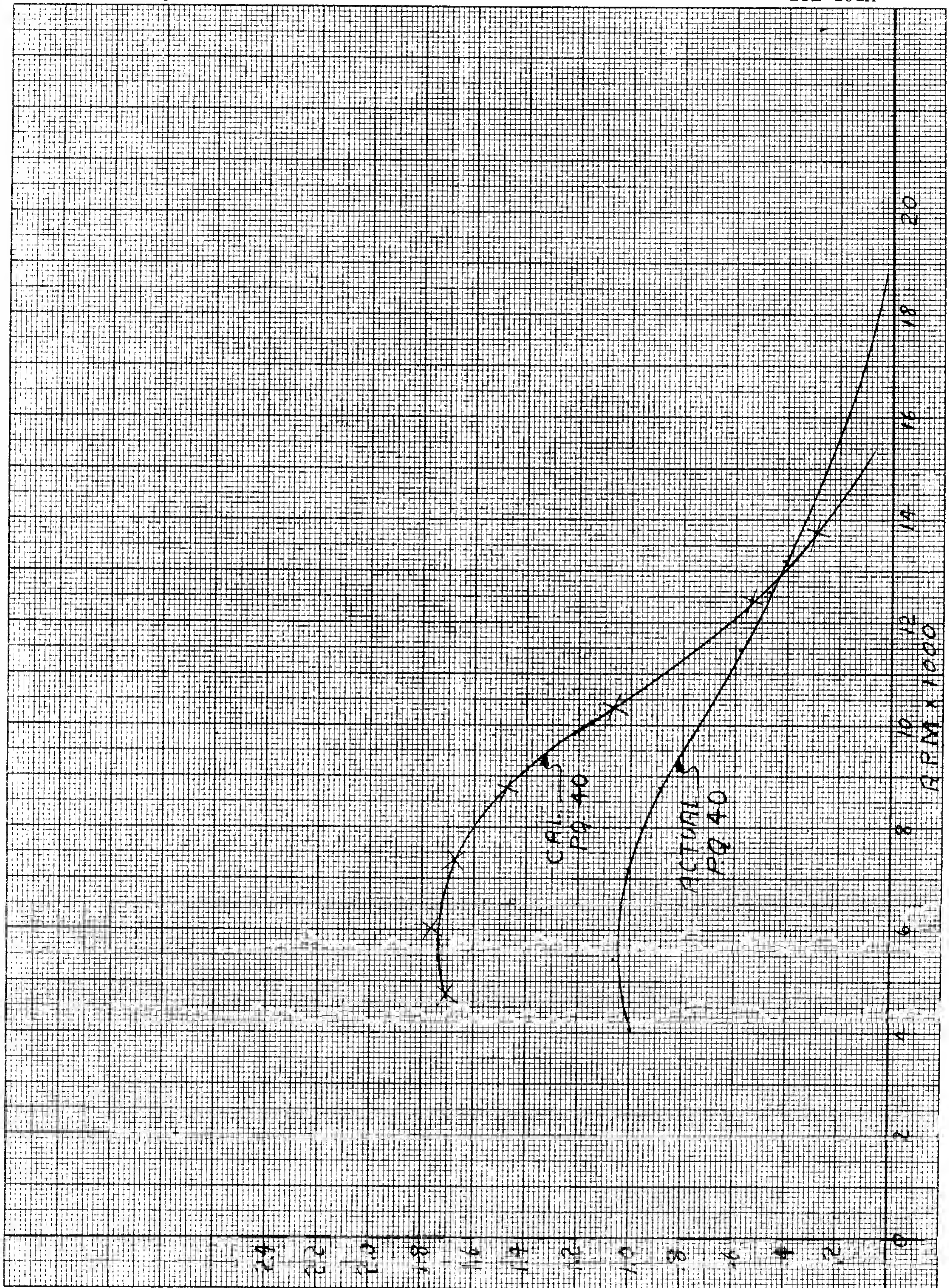
I = current in field (equals armature current)

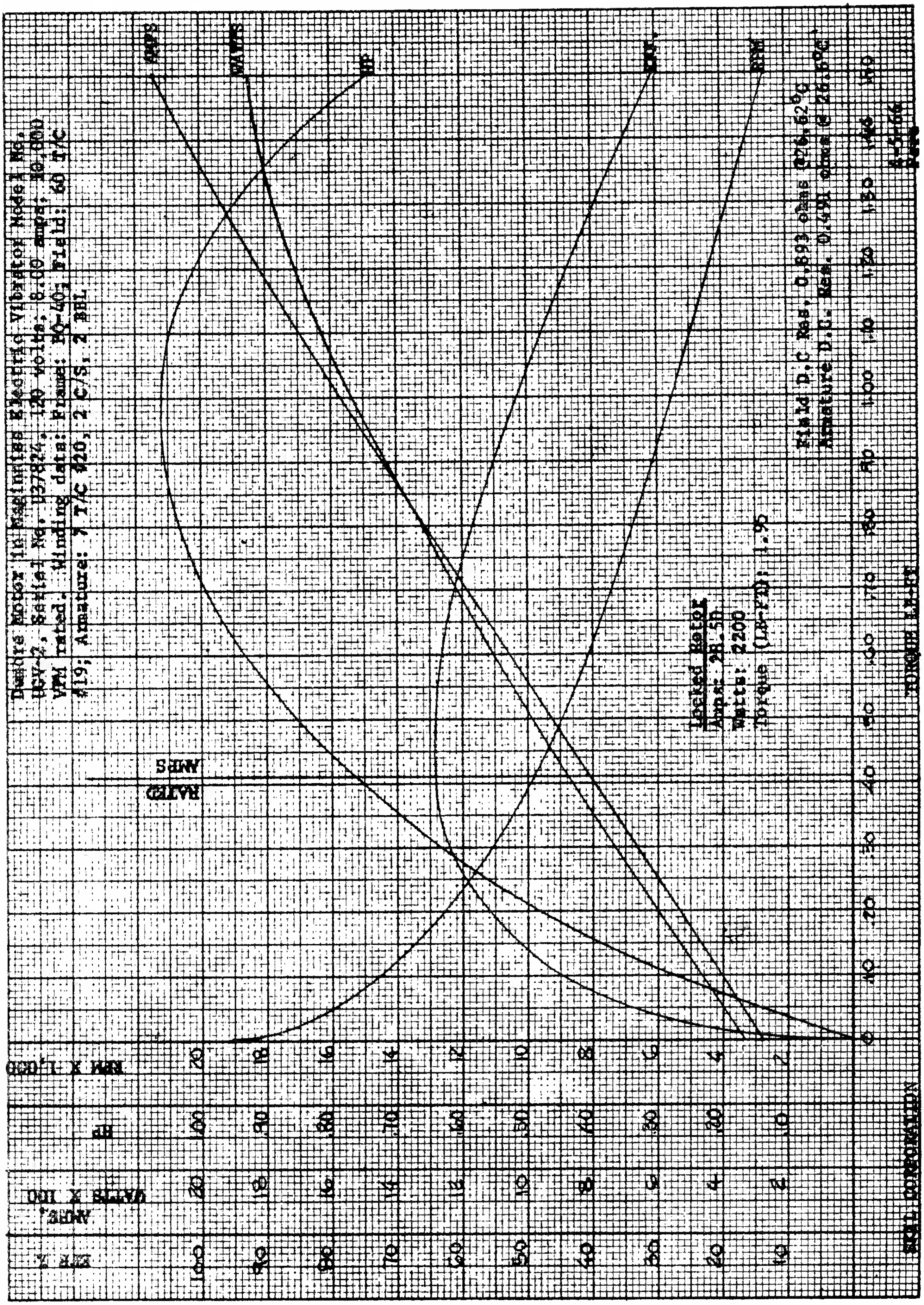
A = cross section area of one air gap in cm^2

References:

Basic Electrical Engineering, Fitzgerald & Higginbotham, Mc Graw-Hill, 1957.
Electric Machinery, Carr, Wiley & Sons, 1958.
Electromechanics, Skilling, Wiley & Sons, 1962.
Electric Machinery, Fitzgerald & Kingsley, Mc Graw-Hill, 1961

Exhibit 6 - Design vs. Actual Performance





E-609
PEO No. 307

Exhibit 8 - Ernie's Calculations

ECL 101A

8-17-66
EGT

PQS-28

NL AMPS 3.8
RPM 16,700
120 VOLTS
12-7-66

MAKE SAMPLES
(TO BE PUT IN APOLLO HOUSING)

ARM - 8 T/C, #20½, 2 C/S

FIELD 70 T/C, #18

$$R_A = \frac{9.85}{12} \times 8\ T/C \times 32\ C \times \frac{11.37}{4000}\ (\text{HPTX}) = .596\Omega$$

$(4)\left(.254\ \frac{LBS}{\Omega}\right)\left(.596\Omega\right)\left(\frac{\$.8325}{LB}\right) = \$.51$

$$R_F = \frac{6.8}{12} \times 70\ T/C \times 2C \times \frac{7.143}{1000}\ (\text{HPTX}) = .566\Omega$$

R_F 12.5% .342 .341 .69 .08

$(.566\Omega)\left(.786\ \frac{LBS}{\Omega}\right)\left(\frac{\$.7755}{LB}\right) = \$.345$

$1.162 \times 1.5 = 1.74\ \Omega$ EFF HOT

ARM MEAN TURN =

FIELD MEAN TURN =

$$ATR = \frac{70 \times 2}{\frac{8 \times 32}{2}} = 1.09$$

$$\frac{R_F}{R_A} = \frac{.566}{.596} = .95$$

120V PERFORM

AMPS	5	10	20	25	30	35	3	
.9PF $V\cos\theta - 2$	106	106	106	106	106	106	106	106
$I(R_A+R_F)$	8.7	17.4	34.8	43.5	52.2	60.8	5.2	
Ea	97.3	88.6	71.2	62.5	53.8	45.2	100.8	
NI 140	700	1400	2800	3500	4200	4900	420	
Ea_1 $\frac{10\ T/C\ 2\ C/S}{10{,}000}$ 1 SL	48	51.2	54.2	55.1	56	56.6	45	
Ea_2 $\frac{8\ T/C\ 2\ C/S}{10{,}000}$ 1¾ SL ×1.4	67.3	71.6	75.8	77.2	78.5	79.4	63	
RPM (x10,000) $\frac{Ea}{Ea_2}$	14.5	12.4	9.4	8.1	6.85	5.7	16	
HP DEVEL. $\frac{Ea \times I}{746}$	.653	1.19	1.91	2.10	2.17	2.12	.405	
F & W	.108	.108	.05	.04	.03	.02	.128	
HP OUT	.545	1.11	1.86	2.06	2.14	2.10	.277	

N.L. Amps - Current drawn by motor operating with no load on it

T/C - Turns per coil

C/S - Coils per slot

R_a - Resistance of armature

R_f - Resistance of field

ATR - Ampere turns ratio

PF - Power factor

* E_{a1} - Counter EMF of standard armature rotating at 10,000 RPM taken from special curve of EMF vs magnetizing ampere turns

SL - Slot length

* E_{a2} - Calculated counter EMF of new armature corrected for changes in stack length and number of turns

* E_a - Counter EMF of armature

F&W - Friction and windage losses

EFF. HOT. means effective hot resistance

Additional Notes:

1. In computing R_a the factor of 11.37/1,000 is divided also by a factor of four because there are 2 paths through the armature.

2. In computing EFF. HOT, the effective hot resistance, the factor of 1.5 is an empirical factor to account for increase in temperature.

* E_a is required for the calculation of developed horsepower.

E_a, E_{a1} and E_{a2} are required for the calculation of the armature speeds at the various loads.

Axial

Centrifugal

Exhibit 11 -- Copy of Test Results of January 12, 1967

ITEM TESTED:

Skil Universal electric vibrator motor (prototype) assembled in Apollo motor housing, with the following motor data:

Frame Size:	PQS-28
Field:	70 T/C No. 18 gauge
Armature:	8 T/C No. 20-1/2 gauge, 2 C/S, 2 BBL

PURPOSE OF TEST:

Engineering data for product evaluation

DESCRIPTION OF TEST:

1. Motor performance was obtained by loading tool with an eddy current dynamometer. The power supply was regulated 120 volts, 60 cycles.

2. Temperature rise was determined by the "rise of resistance" method.

3. After complete assembly of vibrator (that is with core, casing, 1-1/4 inch and 1-3/4 inch heads mounted on vibrator motor), performance of the tool was measured with the fibrator head both in and out of water.

TEST RESULTS:

1. For performance, see attached graph.

2. For complete temperature rise, see attached graph.

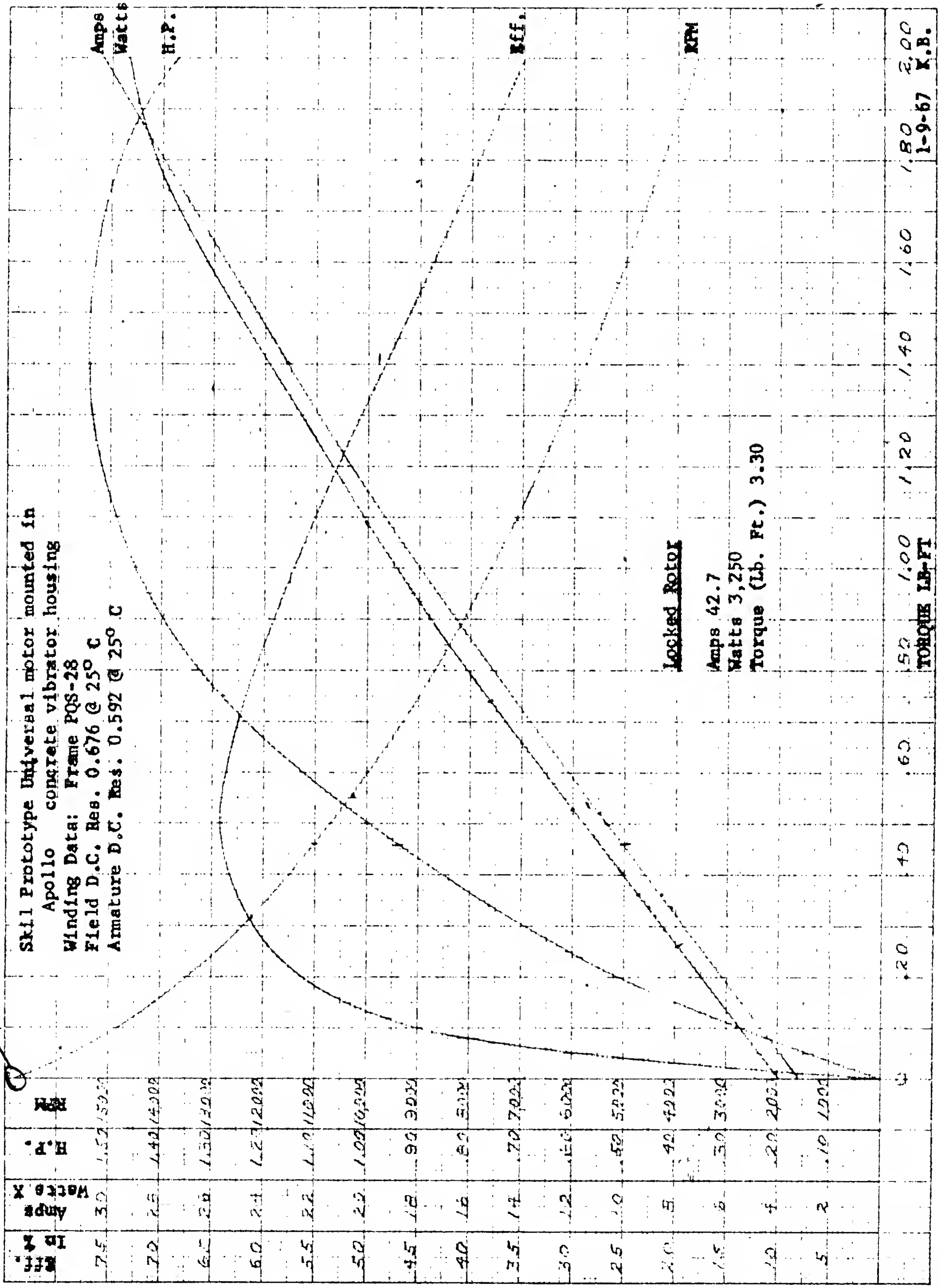
3. Performance of vibrator with vibrator head in and out of water is as follows:

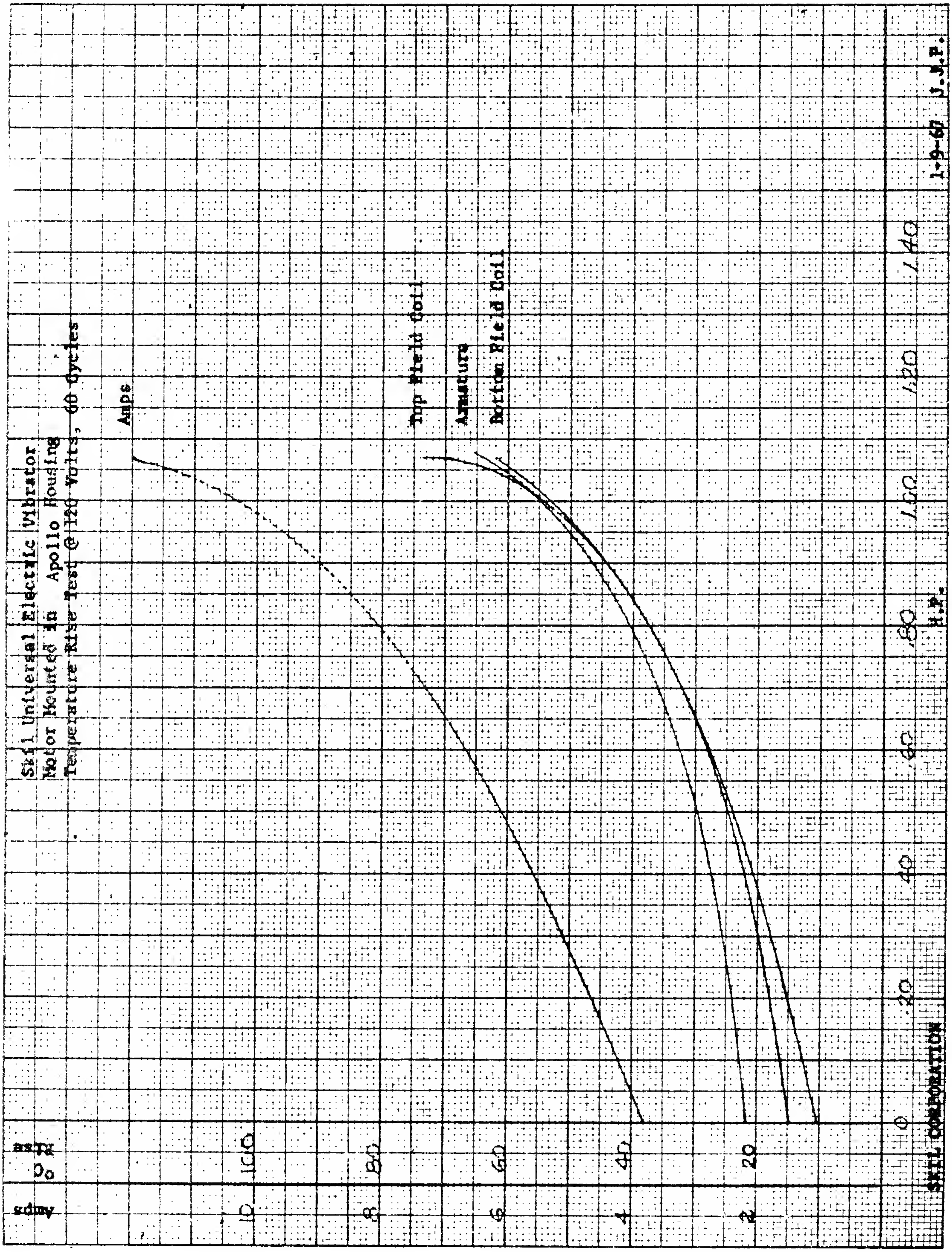
1-1/4 inch Head	Amps	Watts	VPM
In Air	7.96	874	12,400
In Water	7.92	876	12,400
1-3/4 Inch Head	**Amps**	**Watts**	**VPM**
In Air	8.20	880	12,000
In Water	7.04	780	12,800

Graphs attached: 2

CONCLUSION:

None


Skil Prototype Universal motor mounted in
Apollo concrete vibrator housing
Winding Data: Frame PQS-28
Field D.C. Res. 0.676 @ 25° C
Armature D.C. Res. 0.592 @ 25° C
Locked Rotor
Amps 42.7
Watts 3,250
Torque (Lb. Ft.) 3.30
Amps
Watts
H.P.
Eff.
RPM
1670
Eff. In %
Amps
Watts X 100
H.P.
RPM
TORQUE LB-FT
1-9-67 K.B.



Skil Universal Electric Vibrator
Motor Mounted in Apollo Housing
Temperature Rise Test @ 120 Volts, 60 Cycles
Amps
Top Field Coil
Armature
Bottom Field Coil
1-9-67 J.J.P.
H.P.
0
20
40
60
80
100
120
140
Temp °C
Amps
10 100
8 80
6 60
4 40
2 20
SKIL CORPORATION

Exhibit 12 ECL 101A

INTER-OFFICE COMMUNICATION

TO: E. Kossick DATE: May 10, 1967

FROM: Rex Beach SUBJECT: 120V motor for U1V Vibrator

Jerry Palmer has given you copies of the data sheets from the series of tests conducted on the latest motor for the subject vibrator. As you can see, the results are unsatisfactory, since the load speeds are too high for head bearing life. It is desirable to have the load speeds below 11,000 R.P.M.

It would be greatly appreciated if you could expedite this project so that we can obtain a satisfactory motor soon. The U1V series vibrators have been released to production and the pilot run is scheduled for October 1, 1967 with full production scheduled for December 1, 1967.

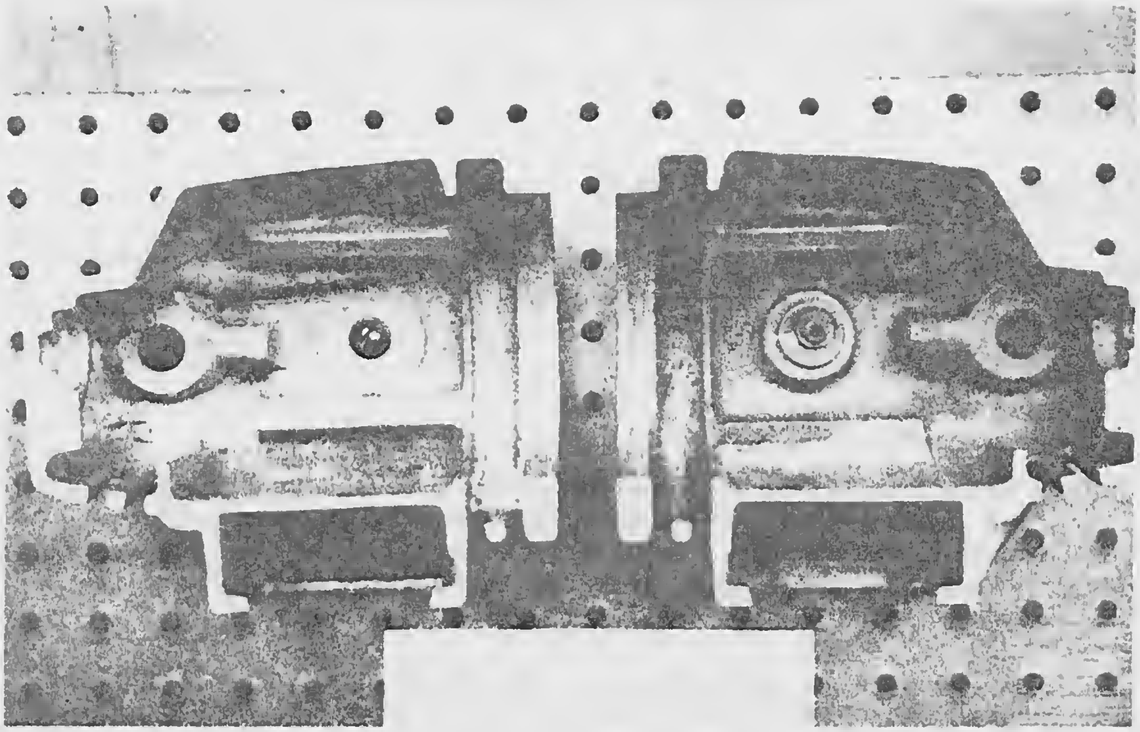
Since we still have a number of tests to conduct (brush life, endurance, etc.), it is necessary that we finalize a motor as soon as possible in order to have a satisfactory motor by the set deadline.

Rex Beach

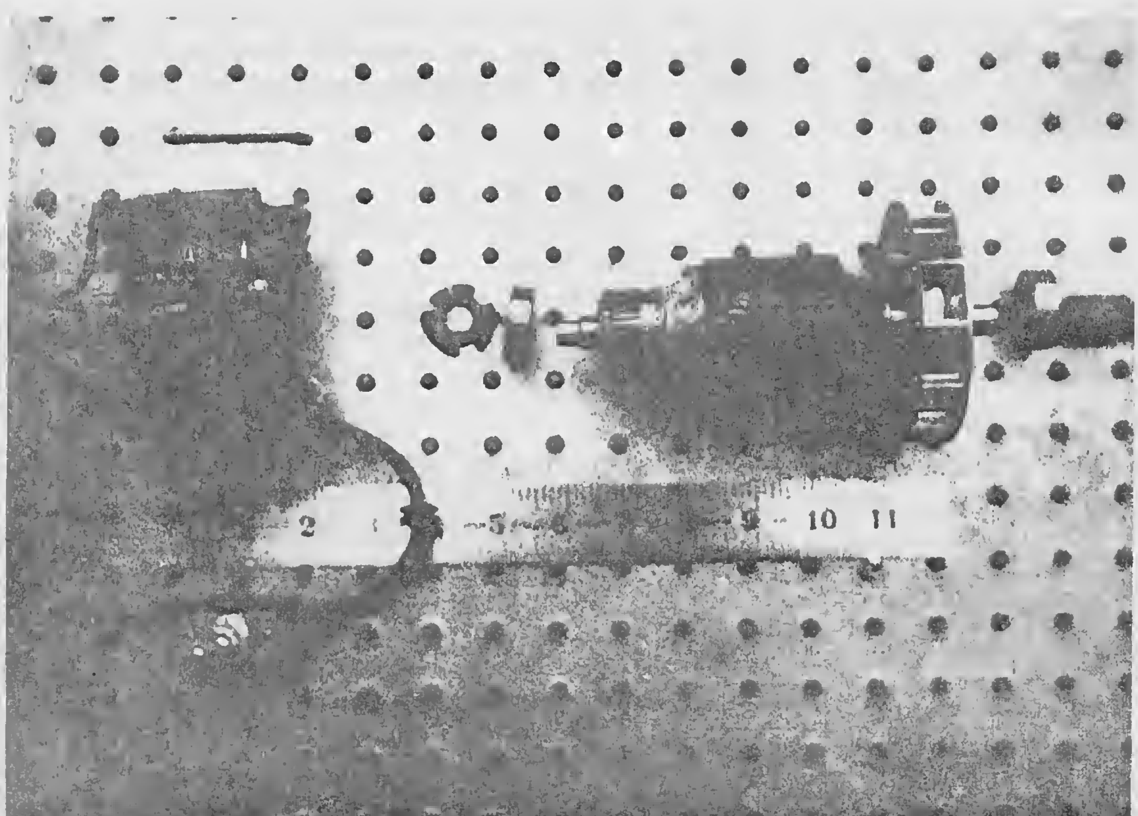
RB:brg

cc P. G. Rebechini
D. Summerfield
G. Palmer
E. F. Etzkorn

Exhibit 13 - Components



Housing



Motor

HEAVY-BUILD COPPER

AWG size	Bare wire diameter (in.) Nom	Minimum insulation increase (in.)	Diameter (in.)			Weight		Resistance		Wires per sq in.	AWG size
			Min	Nom	Max	(lb/ 1000 ft)	(ft/lb)	(ohms/ 1000 ft)	(ohms/lb)		
8	0.1285	0.0033	0.1305	0.1319	0.1332	50.43	19.83	.6281	.0125	57	8
9	0.1144	0.0032	0.1165	0.1177	0.1189	40.01	25.00	.7925	.0198	72	9
10	0.1019	0.0031	0.1040	0.1051	0.1061	31.77	31.48	.9988	.0315	91	10
11	0.0907	0.0030	0.0928	0.0938	0.0948	25.20	39.68	1.261	.0500	113	11
12	0.0808	0.0029	0.0829	0.0838	0.0847	20.01	49.98	1.588	.0794	142	12
13	0.0720	0.0028	0.0741	0.0749	0.0757	15.91	62.85	2.001	.1258	178	13
14	0.0641	0.0032	0.0667	0.0675	0.0682	12.63	79.18	2.524	.1999	219	14
15	0.0571	0.0030	0.0595	0.0602	0.0609	10.03	99.70	3.181	.3171	276	15
16	0.0508	0.0029	0.0532	0.0539	0.0545	7.956	125.8	4.018	.5047	344	16
17	0.0453	0.0028	0.0476	0.0482	0.0488	6.337	157.7	5.054	.7970	430	17
18	0.0403	0.0026	0.0425	0.0431	0.0437	5.021	199.2	6.386	1.272	538	18
19	0.0359	0.0025	0.0380	0.0386	0.0391	3.992	250.6	8.046	2.016	671	19
20	0.0320	0.0023	0.0340	0.0346	0.0351	3.176	314.5	10.13	3.185	835	20
21	0.0285	0.0022	0.0304	0.0309	0.0314	2.525	395.3	12.77	5.048	1,047	21
22	0.0253	0.0021	0.0271	0.0276	0.0281	1.993	502.5	16.20	8.141	1,313	22
23	0.0226	0.0020	0.0244	0.0249	0.0253	1.594	628.9	20.30	12.77	1,613	23
24	0.0201	0.0019	0.0218	0.0223	0.0227	1.266	787.4	25.67	20.21	2,011	24
25	0.0179	0.0018	0.0195	0.0199	0.0203	1.007	990.1	32.37	32.05	2,525	25
26	0.0159	0.0017	0.0174	0.0178	0.0182	.7965	1,256	41.02	51.52	3,156	26
27	0.0142	0.0016	0.0157	0.0161	0.0164	.6356	1,575	51.44	81.02	3,858	27
28	0.0126	0.0016	0.0141	0.0144	0.0147	.5021	1,992	65.31	130.1	4,822	28
29	0.0113	0.0015	0.0127	0.0130	0.0133	.4049	2,469	81.21	200.5	5,917	29
30	0.0100	0.0014	0.0113	0.0116	0.0119	.3178	3,145	103.7	326.2	7,431	30
31	0.0089	0.0013	0.0101	0.0105	0.0108	.2536	3,937	130.9	515.4	9,070	31
32	0.0080	0.0012	0.0091	0.0095	0.0098	.2053	4,878	162.0	790.2	11,080	32
33	0.0071	0.0011	0.0081	0.0085	0.0088	.1623	6,173	205.7	1,270	13,834	33
34	0.0063	0.0010	0.0072	0.0075	0.0078	.1274	7,874	261.3	2,058	17,777	34
35	0.0056	0.0009	0.0064	0.0067	0.0070	.1009	9,901	330.7	3,274	22,276	35
36	0.0050	0.0008	0.0057	0.0060	0.0063	.0806	12,407	414.8	5,146	27,776	36
37	0.0045	0.0008	0.0052	0.0055	0.0057	.0657	15,221	512.1	7,795	33,055	37
38	0.0040	0.0007	0.0046	0.0049	0.0051	.0520	19,230	648.2	12,465	41,649	38
39	0.0035	0.0006	0.0040	0.0043	0.0045	.0399	25,063	846.6	21,218	54,080	39
40	0.0031	0.0006	0.0036	0.0038	0.0040	.0312	32,051	1,079	34,589	69,248	40
41	0.0028	0.0005	0.0032	0.0034	0.0036	.0254	39,370	1,323	52,087	86,501	41
42	0.0025	0.0004	0.0028	0.0030	0.0032	.0201	49,751	1,659	82,537	111,109	42
43	0.0022	0.0004	0.0025	0.0027	0.0029	.0157	63,694	2,143	136,496	137,174	43
44	0.0020	0.0004	0.0023	0.0025	0.0027	.0131	76,336	2,593	197,939	160,000	44

Dave Summerfield, the Chief Electrical Engineer, passed the memorandum along to Ernie Kossick, who was in charge of the Electric Motor Design Group. Dave told Ernie that Skil had purchased a sample of a competitor's vibrator from a hardware store, and the two men decided to adapt a Skil motor to the competitor's housing for testing purposes. They preferred this procedure to that of copying the competitor's motor directly, partly because of the difficulty of determining precisely how an already assembled motor had been made, partly because they expected to save on tooling costs by using Skil motor components, and partly because they believed motors made according to Skil design procedures to be both more economical to make and more efficient. After measuring the inside dimensions of the competitive unit Ernie decided that one of the motors used in a portable Skil power saw was suitable in diameter and power capability. The Skil motor was too long, and to make it fit the housing its stack of field and rotor laminations had to be shortened from the existing 2-1/2 inches down to 1-3/4 inches. This shortening, however, changed the electrical properties of the motor so that it ran too fast in the vibrator, raising for Ernie the question of how to slow it down.

Skil Corporation produced a variety of power tools for applications ranging from hobby shops to construction projects, including electric hand drills, power wrenches, portable saws, motor generator sets and concrete vibrators, some of which were powered electrically and others pneumatically. Electric vibrators with a diameter of over two inches contained the motor in the vibrating head, while smaller ones powered the head remotely through flexible shafts ranging in length from three to ten feet. Operating speeds of all the company's vibrators were between 9,000 and 10,000 RPM and were expected to operate for at least 200 hours without breakdown. Skil considered eight other American firms to be its main competitors in vibrators, and believed them all to be roughly equivalent in sales prices and quality.

The Model UCV-2 Skil vibrator (depicted in Exhibit 2) was one which had come with the Maginiss Electric Company of Mansfield, Ohio, when Skil bought that company out in 1965. Skil salesmen had complained, however, that the

UCV-2 was too bulky, heavy, and expensive to sell, particularly in competition with a vibrator made by the Apollo Corporation.[1] Moreover, in operation the windings of the UCV-2 rose above the 65^{o}C maximum temeprature rise allowed for approval by the Underwriters Laboratories. "A product like this doesn't have to have U.L. approval," Mr. Kossick commented, "but as a matter of company policy we like to have it anyway." The UCV-2 presently reached 94^{o}C in operation. These criticisms of the UCV-2 persuaded the Product Department at Skil, whose mission in the company was to seek new ideas for product development, to recommend redesign of the UCV-2 to the company's Engineering Vice President, who approved it. In discussions with the Chief Engineer it was decided that the project should be undertaken immediately. The target selling price was set at $193 per unit, with a standard 10 foot 1-1/4 inch vibrator head. Other specifications listed by the Product Department appear in Exhibit 3.

One of the competitive vibrators made by Apollo was purchased by Skil and disassembled. Ernie explained; "It was much quicker to start with an Apollo housing, and you never have quite enough time on these projects anyway. If we started by designing a new housing, we would have to complete the styling, mechanical design, all of the detail drawings, make a wood model to verify the styling, have casting patterns made, make castings, and have them machined before we could test the motor. All of this would take from three to four months. But by using a competitive housing for the prototype, we've got it running in about two weeks. And meanwhile, our styling people and engineers are working on the appearance and mechanical design.

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1 Fictitious name of a real competitor.

"We were confident enough of the inside dimensions of the housing to go ahead with design because Apollo is using a motor made by another company in this vibrator which is practically the same diameter as ours. We used to buy the same motor and use it in some of our products. Later we started making a similar motor ourselves and using it in many of our tools. We improved the motor by some of our own design analysis, for instance, making small changes in geometry of the iron which increased the cross section of the magnetic flux paths. We had increased the efficiency and power of the motor and at the same time reduced the amounts of iron and copper, but the diameter was still about the same. Our motor had a diameter of 3.690 inches, and the Apollo housing required 3.688. (Exhibit 4 depicts the field and armature laminations from which the stacks were built up.)

"All we had to do was shorten the stack a little to fit the housing, from 2-1/2" down to 1-3/4" and revise the windings. This saved us still more on the cost of materials, but the trouble was we could see it was also going to make the speed of the motor increase. I wasn't sure how much it would increase because of unknown windage and friction losses, but I figured it could be handled. I'd had quite a bit of experience with these motors, so this one didn't worry me."

The group of which Ernie was in charge was one of four electrical design sections and concentrated exclusively on motors. In addition to Ernie the group included one other electrical engineer, two draftsmen and one motor design trainee. Ernie's experience had included ten years at Skil, five as Assistant Manager of the Motor Testing Laboratory and five as a design engineer. His formal studies had included two years as an Electrical Engineering student at Virginia Tech, plus night courses since leaving there in 1951. He was now within a few units of graduation from the Illinois Institute of Technology.

I was slated to become Manager of the Testing Lab," Ernie said, "but the company started shifting from buying motors to designing and making its own about eight years ago and that opened up more opportunities in design. I find design work a lot more challenging because in design there is less routine and it's a lot easier to see your own contribution to the end product than it is in the lab. Also, there's more and more to do in design because there are always new products and also because new materials and manufacturing processes make it possible for us to redesign and improve the old ones. Right now I would guess our group handles about 25 motor projects, many like this one, per year. Our workload seems to increase about 20% a year. We also carry along some nagging problems which we never seem to have time to solve satisfactorily, such as commutator bars occasionally coming loose and flying off the high speed motors--up to 36,000 RPM--and lead wires on the armatures breaking because of vibration. We manage to get rid of these problems on one motor design at a time, but then come back and apply the solutions to existing motors."

"Practically all the motors we use are the 'universal' type.[2] This is what the concrete vibrator uses. The performance of these motors is hard to predict because the smaller ones have a lot of losses, up to 50% of the input power, which are hard to separate and predict. The reasons we use them are they are very powerful for their weight, they can take an overload well, they have their maximum torque when starting or stalled, they are compact, and they can run on either AC or DC, which lets people run them on battery packs if they want to.

"We usually have to fit a certain diameter motor which depends on the power requirements of the particular application. We have 8 sizes (diameters or frame sizes) from which to choose. The only trouble with these universal motors is that it's almost impossible to accurately predict the performance of a new one without building and testing it. Unfortunately, testing takes too much time and is expensive."

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2 Universal refers to a particular type of motor wiring arrangement which is discussed in Exhibit 5.

(To illustrate the difficulty of predicting performance, Ernie displayed the curves of Exhibit 6 which contrasted design versus actual performance for another motor on which he had recently worked.)

Performance curves for the existing motor in the Maginiss vibrator which was to be replaced by the new design appear in Exhibit 7, from which it can be seen that at the operating point of 10,000 RPM the motor torque was approximately 0.4 foot pounds. Since the same flexible shafts and vibrating head would be used on the new vibrator Ernie concluded that the same torque/speed performance as the Maginiss motor presently delivered would be required on the new unit.

Some calculations which Ernie had made in adapting the motor to the Apollo housing as a prototype of the new unit appear in Exhibit 8. An interpretation of some of the terminology used in these calculations is given in Exhibit 9. The main changes to the motor involved shortening the stack from 2-1/2" to 1-3/4", adding more turns of wire, changing and installing a different fan. "We knew that shortening the stack would raise the speed and that adding more turns would slow it down again. We soon learned that we would not add enough turns because there wasn't enough space in the armature slots. We then decided to try a different cooling fan--one we knew would draw more power and lower the speed but still fit in the same housing. (Photos of the original and new fans appear in Exhibit 10. The die used for casting centrifugal fan cost around $10,000.) The thing was, I didn't know how much more power the other fan would take. It takes more than any other we have, but evidently not enough."

With the new motor and fan installed in the Apollo housing tests were run in the Skil laboratory. The report of these tests appears in Exhibit 11. At the rated current of 10 amperes, the speed was 11,000 RPM and the horsepower was 0.85.* When a flexible shaft and vibrating head were attached to the motor, Ernie was told by the Lab Manager that the new motor drew 7.92 amperes and ran at 12,000 RPM. On May 11, 1967 Ernie's mail included an Inter-Office Memorandum from Mr. Rex Beach of the Construction and Air Tool Division, copies of which had been sent to Mr. Summerfield, Ernie's supervisor and Mr. Rebechini, Chief Engineer of the Division. This memorandum appears in Exhibit 12. Permanent mold tooling had meanwhile been completed for the new Skil housing for the motor. Photos of the motor components and housing casting appear in Exhibit 13.

Ernie was thus faced with the question of how to analyze the problem and proceed. "The main thing theory does for you with these motors is give you some idea about which way to head," he commented. "Raising the resistance of the motor would weaken it and, in effect, reduce its speed under load." This is one way of reducing speed provided that the increase in resistance does not reduce the horsepower below an acceptable value and that it does not increase the temperature of the windings beyond safe limits. "For instance, using 1/2 size smaller wire would increase the armature resistance by about 13% but only raise the overall resistance by about 6%. But the higher armature resistance would also raise the I^2R losses or heat in the windings by the same amount."

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* All Laboratory tests were run using alternating current and 120 volts.

"The best way to reduce speed is to increase the number of turns without decreasing the wire size. For example, there are 8 turns per coil in the armature and we would expect the speed to decrease about 1/8 if we added one more turn. But there are 16 slots in the armature stack with 2 coils per slot. This makes four coil sides or 32 conductors per slot, and that pretty well fills the slots with no room left for adding more turns. To increase the slot size, we'd have to make new tooling for the laminations which would cost too much--and besides, it would reduce the area of the magnetic paths and degrade the performance of the motor and all the other motors which use the same laminations." Exhibit 14 presents data on the wire used for the vibrator motor windings.

Exhibit 1

ECL 101A

INTER-OFFICE COMMUNICATION

TO: Dave Summerfield

DATE: May 12, 1966

FROM: Elmer F. Etzkorn

SUBJECT: PEO 310 Skil Vibrator Motor

We are now starting to design a completely new UCV2 Skil flexible shaft vibrator. In order to proceed with the layout drawing, we will need a dimensional motor outline drawing as soon as possible.

According to our preliminary investigations, we will require a motor with the following general specifications.

1. No load speed not to exceed 18000 RPM (prefer 16000 to 17000).
2. Must have a maximum horsepower of 1.25 (minimum).
3. Must be rated at 0.90-0.95 HP and the temperature rise at rated horsepower must not exceed 65° C by the rise of resistance method.
4. Ampere rating should be around 10 amperes.
5. Speed at rated horsepower must be in the 9500 to 11000 RPM range.
6. Must be capable of operating continuously at rated horsepower (amperes) without overheating or motor burnout.
7. Brush life should exceed 150 hours continuous operation.
8. Commutator life should exceed three sets of brushes.
9. Must have sufficient torque at rated horsepower to operate a 1-3/4 head with 20 feet flexible shaft drive and stay within rated horsepower of the motor.
10. Fan to deliver 50 C.F.M. free air (minimum).

If you require any additional information, please call me. We have been requested to release this project to production by October, 1966.

Elmer F. Etzkorn

EFE;brg

cc P. C. Rebechini

SKIL | CONSTRUCTION EQUIPMENT

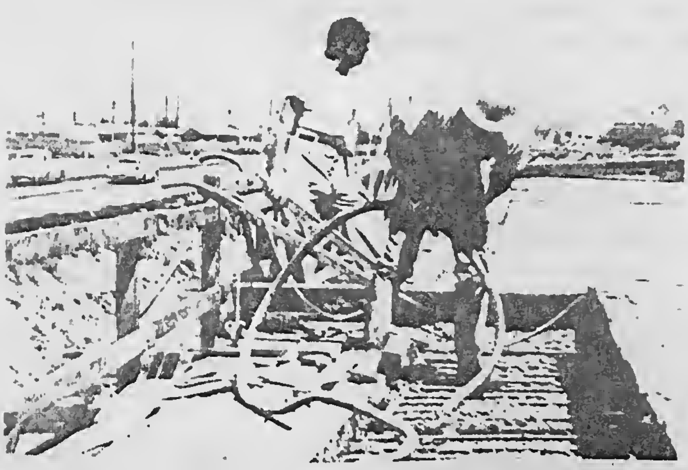
concrete vibrators

HI-LECTRIC & UNI-LECTRIC

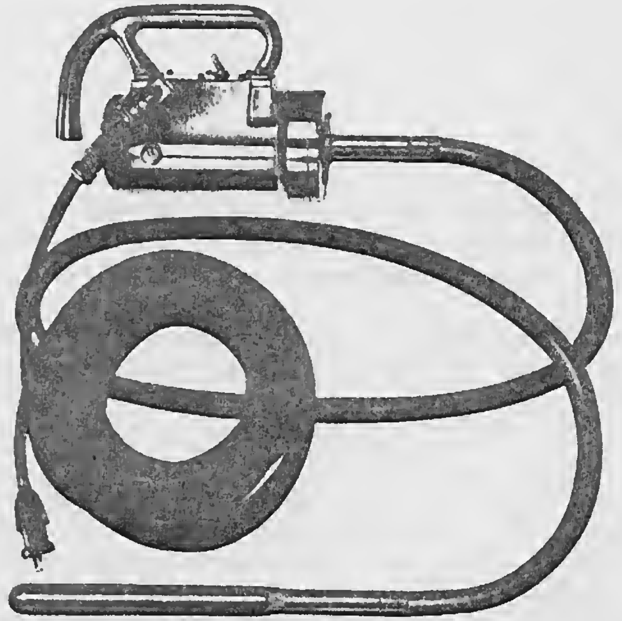
Skil Concrete Vibrators economically speed concrete placement with high frequency, low amplitude vibration. Contractors are now able to easily place concrete into corners and flush against forms, eliminate voids and produce excellent bond. Concrete has greater strength because dense, low slump mixes may be used.

Skil Vibrators are available with Hi-Lectric or Uni-Lectric motors, with many different models to choose from. They are lightweight, easily controlled by one man, and Hi-Lectric models can draw their power from as far as 200 feet away. Each is designed to meet the rigid performance standards required in modern concrete pouring operations.

Skil Concrete Vibrators are effective in producing the desired results in slab work, wall forms, footings, culverts and columns.



1¼" & 1¾" FLEXIBLE SHAFT VARIATIONS



The "Pencil Vibrator", available with interchangeable heads in 1¼" or 1¾" diameters, produces quality work free of surface blemishes. Reaches the hard-to-work places and is particularly effective on pre-stressed beams, encased steel beams and any areas with closely spaced reinforcing steel. Recommended for use on thin slabs, thin walls, under lintels and monolithic pours. Available in 6 models featuring a choice of 2 head diameters and 3 shaft lengths.

POWER: *115 volt — 180 cycle — 3 phase*

SPECIFICATIONS:

MODEL NO.	MAX. SPEED VPM	HEAD SIZE DIA. IN.	HEAD SIZE LGTH. IN.	FLEXIBLE SHAFT LGTH. FT.	SHAFT O.D. IN.	NET WT. LBS.	SHPG. WT. LBS.
H3V-C3	10,500	1¼	10¾	3	1 1/16	23½	27
H3V-C7	10,500	1¼	10¾	7	1 1/16	27¼	30¾
H3V-C10	10,500	1¼	10¾	10	1 1/16	30¼	33¾
H3V-E3	10,500	1¾	9	3	1 1/16	24¾	28
H3V-E7	10,500	1¾	9	7	1 1/16	28½	31¾
H3V-E10	10,500	1¾	9	10	1 1/16	31½	34¾

PRODUCT ENGINEERING ORDER

PEO No. 310 Assigned to: Rex Beach Issue No.1

Sept. 9, 1966

GENERAL SCOPE AND PURPOSE: Design, detail, develop and release for manufacturing a series of Flexible Shaft Concrete Vibrators to replace the present models 58001, 58003 (UCV-2) Vibrators. These units to consist of motor, flexible shaft and vibrator head.

MODEL NO.	HEAD DIA.	SHAFT LENGTH
58000-T1-00	1 inch	18 inches
58000-T1-31	1 inch	5 ft.
58000-T1-32	1 inch	10 ft.
58001-T2-00	1-1/4 inches	18 inches
58001-T2-31	1-1/4 inches	5 ft.
58001-T2-32	1-1/4 inches	10 ft.
58002-T1-00	1-1/2 inches	18 inches
58002-T1-31	1-1/2 inches	5 ft.
58002-T1-32	1-1/2 inches	10 ft.
58003-T1-00	1-3/4 inches	18 inches
58003-T2-31	1-3/4 inches	5 ft.
58003-T2-32	1-3/4 inches	10 ft.

DESIGN SPECIFICATIONS:

MOTOR UNIT

Speed: 16000-18000 R.P.M. free - 9500-11000 at rated H.P.

Horse Power: .9 - .95 rated. Actual max. H.P. of at least 1.25.

Volts: 110/120 AC/DC Amps - 10 approx.

Weight: 13 lbs. max.

Construction Features:

1 - Cast aluminum housing.
2 - Design swivel handle with appropriate lock.
3 - Drip-Proof construction.
4 - 18" power cord with twist lock plug.
5 - Sufficient torque to drive 1-3/4" head with 20 ft. flexible shaft within rated H.P. of the motor.
6 - Provide for shoulder strap to be used as accesory.

Remarks: Make available a 2-1/2 H.P. Gasoline Engine Power Unit.

ERNIE KOSSICK (B)

Ernie's decision was to raise resistance in the armature by using smaller gage wire. In place of 8 turns per coil of 20-1/2 gage wire he asked the shop to make an armature with 8 turns per coil of 21 gage wire and install it in the same housing with the same field coils. This motor was assembled and tested in the lab and compared with the original armature producing the results shown in Exhibit B1. Ernie noted that the speed was still too high. Data on another motor with the high resistance armature appears in Exhibit B2.

"We were giving 11,000 RPM at rated current as we had been asked to," Ernie commented, "but evidently the load was less than we were told. Raising the armature resistance 13% with the smaller wire should have reduced the speed sufficiently, but according to the Product Test Lab it didn't, though frankly I don't understand why.

Prepared in the Design Division, Department of Mechanical Engineering, Stanford University, by Mr. Karl H. Vesper, with financial support from the National Science Foundation. The helpful cooperation of Mr. Ernie Kossick and Skil Corporation in making this material available is gratefully acknowledged.

"So we decided to try raising resistance and flux in the field by changing from 70 turns per coil of 18 gage wire to 80 turns per coil of 19 gage wire. This gave us a no-load speed of 15,756 RPM, a speed of 11,750 RPM at 7.3 amps and 9,400 RPM at 10.8 amps. Since 7.3 is close to what the amperage should be, this seemed like a fairly satisfactory answer.

"But Beach's group decided to use this field with the original armature since test lab results showed the original armature to have a lower speed than the one with higher resistance. This seemed to them like the logical approach, to combine all the slowest parts."

Test lab results of this motor appear in Exhibit B3.

SHAFT LENGTH	HEAD DIA.	OPERATING IN WATER 1st ARMATURE WATTS	AMPS	RPM	2ND ARMATURE WATTS	AMPS	RPM	OPERATING IN AIR 5/6/61 1st ARMATURE WATTS	AMPS	RPM	2ND ARMATURE WATTS	AMPS	RPM
5 FT.	1 1/4	844	7.68	12700	805	7.20	12300	834	7.52	12,800	785	7.05	12900
	1 1/2	1092	9.01	11,700	1024	9.16	11600	912	8.4	12050	810	9.20	12600
	1 3/4	720	7.0	13000	820	7.3	12900	790	7.1	12900	810	7.25	12800
20 FT.	1 1/4	806	7.2	12850	820	7.2	13000	760	6.7	13200	840	7.5	12850
	1 1/2	1000	9.26	11600	1020	9.2	11750	900	8.16	12200	960	8.6	12400
	1 3/4	860	7.1	12800	798	7.0	13150	820	7.26	12780	804	7.1	13100

THIS DATA RECORDED WAS A RESULT OF USING 2 DIFFERENT ARMATURES IN THE SAME HOUSING & POWERING THE SAME HEADS & SHAFTS

Exhibit B2

ECL 101B

SKIL CORPORATION
PRODUCT TEST LABORATORY
PERFORMANCE DATA SHEET

A - 8T/C #. 21
F - 70T/C #18

REQUEST NO. E 661 DATE 5-2-67

P.E.O. NO. 310 TESTED BY

DESCRIPTION 3rd Unit Armature Change (Redesign To reduce Speed)

MODEL UV TYPE 1 VOLTS 120 CYCLES 60 PHASE

ARMATURE NO. ARMATURE SPEC. D.C.RES. OHMS

BARS SLOTS BBL ARMATURE ROTATION CW CE AMB. TEMP. 28

FIELD NO. FIELD SPEC. D.C.RES. OHMS

FRAME MOTOR TYPE: DIST. ☐ SAL. ☐ REV. ☐ GEAR RATIO STAGES

TESTED AT: VOLTS 120 CYCLES 60 PHASE

TESTED IN High Speed Dyno TORQUE ARM 1 ft

INSTRUMENT NOS.

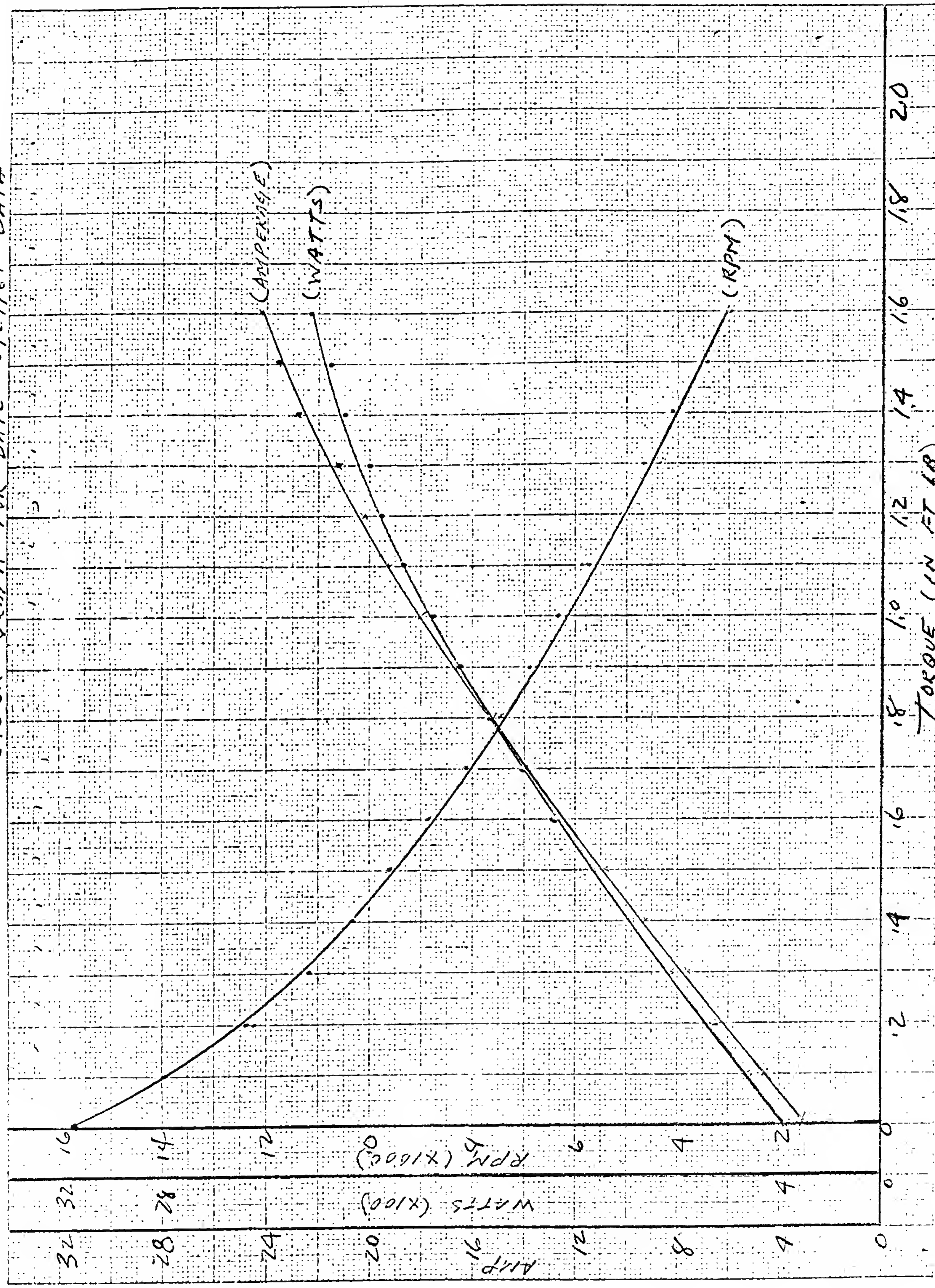
AMPS	WATTS	R.P.M.	LBS. OZ.	LB-FT OZ-IN	OUTPUT H.P.	OUTPUT WATTS	EFF.	P.F.	
3.85	450	16575					Free Speed		
4.10	490	16200					IN Dynometer		
7.90	860	12650	.25		.61				
11.0	1250	10500	.50		1.01				
15.5	1650	9000	.75		1.29				
18.0	1950	7780	1.00		1.48				
22.0	2300	6500	1.25		1.55				
25.0	2550	5500	1.50		1.57				
28.0	2950	4500	1.75		1.50				
		Torque & Tare	Tare	Net Torque					
					LOCKED ROTOR				

X - 8 Arm
9 - Z Field

SKIL CORPORATION
PRODUCT TEST LABORATORY
PERFORMANCE DATA SHEET

REQUEST NO. E661 DATE 6/29/67
P.E.O. NO. 310 TESTED BY S.G. C.Y.L.
DESCRIPTION FLV Vibrator Same Unit as #5 rerun Not Enough points Taken for positive data
MODEL — TYPE — VOLTS 120 CYCLES 60 PHASE Single
ARMATURE NO. 8-X ARMATURE SPEC. 8 T/C #20 1/2-2 S D.C. RES. .5680 OHMS
BARS 32 SLOTS 16 BBL 2 ARMATURE ROTATION CWCE AMB. TEMP. 27 °C
FIELD NO. 9-8 FIELD SPEC. 80 T/C #19 D.C. RES. .974 OHMS
FRAME ___ MOTOR TYPE: DIST. ☐ SAL. ☑ REV. ☐ GEAR RATIO Direct STAGES —
TESTED AT: VOLTS 120 CYCLES 60 PHASE Single
TESTED IN High Speed TORQUE ARM 1 FT
INSTRUMENT NOS. ___

AMPS	WATTS	R.P.M.	LBS. ~~OZ.~~	LB-FT ~~OZ-IN~~	OUTPUT H.P.	OUTPUT WATTS	EFF.	P.F.	
X 3.40	380	15400	—	—	—	—	—	(IN High Speed DYNO)	
4.00	516	13900	0.10		.265	197.5	38.3		
6.10	626	12400	0.20		.472	352	56.2		
7.80	812	11250	0.30		.642	479	59.0		
9.00	980	10300	0.40		.785	585	59.6		
10.4	1178	9600	0.50		.914	682	60.5	✓	
12.10	1260	8850	0.60		1.01	753	59.7		
13.92	1400	8100	0.70		1.078	805	57.5		
15.20	1580	7500	0.80		1.14	852	56.0		
—	1640	6900	0.90		1.18	882	53.7		
—	1760	6375	1.00		1.215	906	51.5		
—	1870	5725	1.10		1.22	910	48.7		
75.5	1950	5100	1.20		1.165	869	44.6		
		Torque & Tare	Tare	Net Torque					
					LOCKED ROTOR				


CHECK GRAPH FOR DATE 6/29/67 DATA
(AMPERAGE)
(WATTS)
(RPM)
TORQUE (IN FT LB)
RPM (X1000)
WATTS (X100)
AMP